A STUDY OF THE GATING SYSTEM OF CASTINGS PRODUCED BY THE FULL-MOLD PROCESS

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

INTRODUCTION

A metal casting can be made by different methods by conventional sand molding such as green, dry, shell or CO_2 molding. There are methods such as investment casting, die casting, centrifugal casting by which castings can also be made but these are different in methodology than the conventional green sand molding. In green sand molding for producing castings, a cavity is created within the mold through the use of a pattern which has the same general shape as the desired finished casting. Molding sand is packed around the pattern. The pattern is loosened by vibrating or tapping. The pattern is provided with a taper on the sides to help in removing it from the mold. The pattern may be either of wood or of metal, most generally, or of some other material. In each of the conventional sand molding methods, the pattern is removed from the mold, leaving a cavity. Molten metal is then poured into the mold cavity, which when solidified, produces the desired metal casting.

A new process called the full-mold process has been developed in the last few years. By this process, a metal casting is made by using a pattern made of foamed plastic. This pattern is placed in a flask and sand is packed around it. Unlike the above conventional sand molding techniques the pattern is left inside the mold. Molten metal is poured directly into the mold which still contains the pattern. The molten metal replaces the foam pattern which vaporizes, leaving a metal casting of the same shape as the pattern. This is one of the simplest processes to produce a casting.

There is a great variation and difference between the conventional sand molding processes and full-mold process in the methodology of the processes. Analysis and research remains to be done in areas such as gating system design,

ventilation, surface finish, pouring temperature, pouring rate, dynamics of metal flow, and numerous metallurgical effects. The gating system, no matter which molding method or process is used to make a casting, is one of the major areas to which attention should be given. A good design of the gating system can reduce the percentage of defective castings to a large extent. Castings are scrapped through lack of a little practical knowledge on such fundamentals as gating, pouring, shrink heads and suitable pressure for either light or heavy castings. A considerable amount of research has been done for conventional molding methods with regard to the gating system resulting in the development of basically acceptable rules of thumb for the dimensions of each part of the gating system required to provide sound castings.

An attempt has been made in this experimental research to see if the rules of thumb for the dimensions of each part of the gating system used in the conventional process, will work for the full-mold process and to determine the best location for the gates and risers.

History of the Full-mold Process

H. F. Shroyer first used foamed plastic material as investment patterns for the production of art castings on April 15, 1958. Since the material has good combustibility, Shroyer attempted to leave the pattern embedded in the mold and to gasify it when the molten metal entered the mold. He originated the principle of the full-mold process. About half a year later H. Nellen carried out similar experiments.[1]

Industrial application of the full-mold process was promoted by Wittmosser in Europe after Grunzweig and Hartmann purchased the patent from Shroyer. The first commercial use of the process came in Germany in 1962. The first commercial castings produced by the process in the United States

was in Detroit on June 26, 1963. In the first year after its introduction to commercial use 12,000 tons of castings were produced ranging in size from a few pounds to 30 tons.[2]

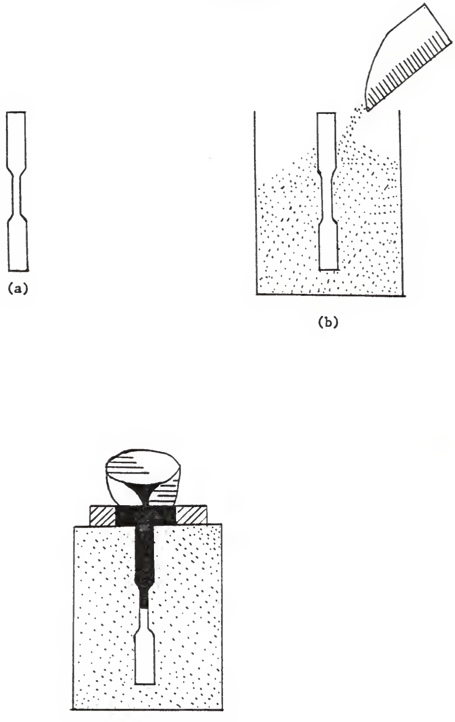
In 1962, Clarke[3] claimed to be the first sculptor to have seen the merits of the process. In the same year Duca et al.[4] described research at Massachusetts Institute of Technology on art casting which was dedicated to developing practical and economical means for art castings by American foundry methods and to awakening or rekindling the interest of sculptors, foundrymen and architects in this field. The paper deals primarily with work done to date on the foam vaporization methods of casting metal sculpture. In 1963, Wittmoser[5] explored potentialities of the full-mold process in a number of specific foundry production areas and indicated some general inherent advantages the process offers over conventional molding methods. In 1964, another patent[6] was granted for the use of unbonded sand for the cavityless casting method (another name sometimes used for the full-mold process). Most of the conventional sand molding processes have been in use for thousands of years, the capabilities and limitations of the traditional methods are well known to foundrymen. When using unbonded sand, the new technique is so radically different from past methods that observers are generally skeptical even after having seen the process work. Unbonded sand has practically no clay content or any other binders added to the sand. In 1966, Srinogesh and Govind[7] conducted some experiments to evaluate the effect of grain size and pattern coatings on surface finish and strength of castings produced by the full-mold process using unbonded sand. It was found that finer sand grains and thicker coats favored production of castings with a smoother surface. In 1967, Dieter and Paoli[8] showed that a most important and unprecedented feature of the

full-mold process is that the unbonded sand may be used, opening a new field for foundry development. Butler and Pope[9] have published a comprehensive review of the method and an investigation of the possibilities. The review includes photographic studies made through glass windows of metals flowing into full-molds made in unbonded sand. The photos reveal that the phenomena which take place are very different from those which take place in ordinary molds made of bonded sand.

Lee[10] has studied the gating of full-mold castings with unbonded sand molds. By using high-speed motion picture films, he studied how a full-mold casting fills when poured. Top-gating, bottom-gating, and side-gating were studied. Molds were poured in aluminum and cast iron. The study shows that the first stage of filling takes place at an accelerating rate, but the second stage of filling is retarded by gas evolution from the pattern.

Principles of The Full-mold Process

A casting can be made by the full-mold process using various common foundry sands and binders or using unbonded sand as shown in Fig. 1. The ingredients of molding sands are clay, water and the principle sand constituent, SiO_2. These three components provide the bulk and plasticity required of the molding sand. Other materials such as bentonite and fire clay may be added to the sand mixture to develop the proper strength and plasticity of the molding sand. The unbonded sand does not contain any binder or clay content. The pattern used is polyurethane or styrofoam. This material can be carved to any shape as desired. By this process practically any type of castings can be produced. In castings of the type which require cores for creating cavities or holes in the casting when produced by conventional methods, cores are not required in the full-mold process. The molding sand



(a)

(b)

(c)

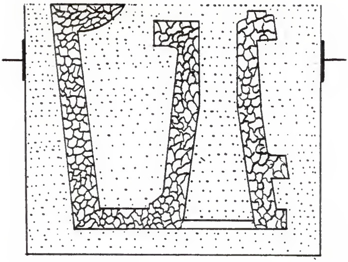
Fig. 1. Mold-making and filling the mold by molten metal.

(a) Pattern
(b) Pattern is buried in sand.
(c) Pattern is replaced by metal.

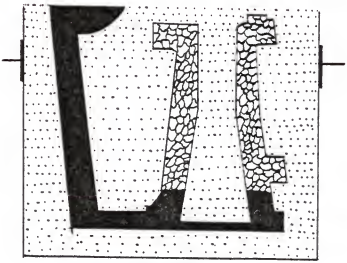
used for making the mold is used to fill the holes needed in the castings as shown in Fig. 2. It is not necessary to pack the sand as tightly as it is done in the conventional molding processes. As the pattern is replaced by molten metal, the resulting gas pressure, the condensed products of vaporization, the refractory pattern coating, and the metal itself all combine to support the sand and maintain the rigid structure of the mold. Coatings are usually applied to the pattern to produce a better surface finish on the castings.

A totally different phenomena than for the conventional sand molding processes occurs as metal is being poured into the mold. The metal tends to replace foam in a radial direction from the point of entry as shown in Fig.3. Castings which are top gated can actually be made to fill from the top down, the metal descending like a curtain while the foam vaporizes and vanishes. Variables such as foam density, foam chemistry, foam vaporization rate, foam moisture content, pattern size, pattern weight, pattern surface finish, pattern strength, coating chemistry, coating permeability, coating strength, coating thickness, coating refractory properties, sand permeability, sand grain size distribution, sand moisture content, sand compaction, sand strength, sand refractory properties, sand density, sand temperature, gating system, mold weights required, flask size, flask permeability, metallurgy, metal temperature, metal weight and yield, atmospheric moisture, costs and time cycle should be considered for the development of the process. Each of the above variables could be reduced by quality control procedures to the manageable state of constants.

<u>Patterns</u>. The pattern material used in the full-mold process is styrofoam. Styrofoam is an insulating material usually recognized for its



One-piece pattern without core



During casting

Fig. 2. Use of molding sand for filling the holes and depressions in the casting to avoid the use of cores.

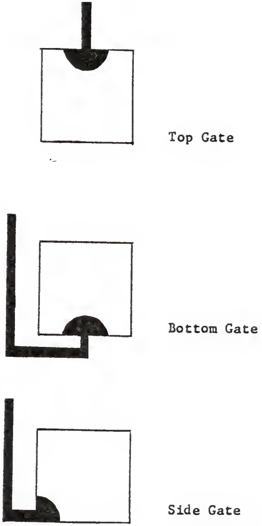


Fig. 3. Molten metal replacing the syrofoam pattern for three different locations of the gating system.

applications in construction work and packaging. The density of the styrofoam used in the full-mold process should be in the range of 1 to 1.2 pounds per cubic foot with compressive strength of 13 to 15 psi. This material can be obtained as sheets 4 feet by 12 feet, with thickness varying up to 17 inches. For stability, the material should have been cured properly by aging for one month. Patterns can be individually fabricated or production molded. In making patterns, no parting line is needed. It is possible to make different sections of a pattern separately to be joined together with an adhesive. Band saws with knife-edge blades can be used to cut the styrofoam. Woodworking tools can be used to make the patterns. Impressions of woodworking tool marks will appear on the casting as on the pattern made. Heated nichrome wire or a thin blade can be used to cut the material. Finishes of molded patterns are generally better than fabricated ones.

Patterns can be molded by making an aluminum mold with a steam jacket and ports with suitable ejectors. Polystyrene beads are given a preliminary expansion in a pre-expander before they are injected into the mold. They are further expanded with steam in the mold. The mold is then chilled and the pattern ejected from the mold mechanically on electrically controlled time cycles.[8] The various parts of the patterns are glued together and coated with refractory materials and attached to the gating system, which is usually made separately. The different characteristics of the styrofoam make it versatile for making patterns. Due to the characteristics of the styrofoam, the production costs in different areas such as pattern making, casting cleaning, core making, molding, design and production planning can be reduced.

Coatings. Coatings of different refractory materials may be applied to the pattern. Water-base coating mixes are made of zircon flour, plaster of

paris, dolomite, iron oxide, alumina, coaldust, silica flour and magnesite fines, all of size -150. Dextrine or bentonite is used as a binder. Magnesite, sillimanite, silica flour and coaldust are effective in improving surface finish. Zircon, alumina and iron oxide give higher strengths. A precoating of wax may be applied by dipping patterns in a bath of paraffin at 80° C before the refractory coat is applied.[7]

Surface finish. Methods for improved surface finish include the application of tissue paper, wax or fabric to the pattern surface. A pasty mixture of flour, water and polyvinyl-acetate emulsion is first painted on the pattern surface and allowed to dry. Tissue paper is then dipped in alcohol and laid on the pattern surface much like gold leaf. Wax coatings over patterns can also be used to alter casting texture. The wax coatings also are vaporized by the metal entering the mold.[4]

Sand properties. Some of the usual sand properties of concern in conventional sand molding techniques do not need to be as thoroughly considered in the full-mold process. Permeability, grain size, insulation, refractory, compaction, moisture content, and temperature should be considered. Grain size of the sand does not effect the casting surface if a refractory coating is used on the pattern. If small grain size of sand is used, the permeability is reduced. Sand with a single sieve size is recommended.[8] The grain size is usually determined for different castings by trial and error methods. Sand with high permeability should be used to get the best castings. Gases are trapped if the sand is impermeable and possibly blow the metal out the sprue. This is one of the important characteristics of the sand. Unbonded sand is an excellent insulator with a thermal conductivity almost as low as

crude asbestos. Compactness of the sand can be measured by taking the volume difference before and after the sand is compacted.

The gating system. The gating system is one of the main areas which should be considered in producing a casting, no matter which molding process is used. Bad design of the gating system can result in defects in the castings. One of the main variables which should be considered when designing a gating system is the flow of molten metal while filling the mold. It was found[8] that the molten metal tends to replace foam in a radial direction from the point of entry. The size, the shape and the location of the gating system to the casting are also major variables. It is quite possible that a non-conventional shape will have to be used. The sprue is a most important and critical part of the gating system. Runners of any shape can be used. Gates such as top gates, bottom gates, multiple gates, pencil gates, knife gates and horn gates can be used. It is essential to run a number of preliminary test castings to come to a definite sprue design.

Pattern material and pouring. Styrofoam begins to vaporize at 400° F (204° C) but it actually begins to collapse at 170° F (77° C). Decomposition of the styrofoam occurs at such slow rates that the metal will often chill before the styrofoam is completely vaporized, thus the use of styrofoams with densities above 2 pounds per cubic foot is not practical. Since in this study aluminum was the casting metal used, its behavior and characteristics will be primarily considered here. In aluminum castings it is considered good practice to pour at the lowest temperature which will give consistently good castings. Superheating can cause alloy deterioration and increase gas porosity. Therefore it is advisable not to superheat the metal but rather to

resort to lower density foams which will vaporize more readily. More critical than temperature is the pouring technique. For small castings, the essential rapid pouring is easily achieved by using pouring basin stoppers. In furan bonded sand, large castings of up to 35 tons have been poured successfully. A pouring rate of 300 pounds per second has been proposed for castings in the range of 1 to 5 tons.[8] Molten metal should be poured at temperatures sufficient to vaporize the styrofoam and at a pouring rate ample to prevent catastrophic failure. When pouring manually, sensible caution and considerable training is necessary to maintain an accurate pouring rate. On the production line, the pouring rate can be controlled more easily by mechanical devices.

Basic Casting-Design Considerations

Many factors are involved in producing a good casting. A casting is designed to serve some purpose and to satisfy this purpose the casting should have certain properties and characteristics. In order to achieve the properties and characteristics needed, a number of details should be observed and every detail should be observed faithfully and should co-ordinate in orderly sequence with the others. Details such as the gating system, molding practices, the temperature and the rate of pouring of the metal, and venting are important.

Among these, the design of the gating system is very important in order to produce a good casting. A gating system should introduce the metal into the mold cavity in such a manner that avoids formation of casting defects such as laps, sand erosion and spalling, slag or dross inclusions, gas cavities and shrinkage. At the same time, the yield of the casting should be maintained as high as possible and the cost of gate removal minimized.

To function satisfactorily, good gating and feeding systems must take into account certain well known characteristics of aluminum casting alloys, namely:

1. drossing tendency,
2. gas entrainment,
3. gas absorption,
4. solidification shrinkage,
5. difficulty of eliminating microshrinkage, and
6. high thermal conductivity.

Oxidation of molten aluminum and hydrogen absorption can occur readily in the mold and during pouring. Oxygen and water vapor from the atmosphere and mold gases are abundantly present. When the metal flows through the gates, gases can mix in the molten metal and may form bubbles inside the flowing metal. When the metal solidifies the bubbles may remain there and form holes in the casting. Dissolved gases in the liquid aluminum causes more trouble. Solubility of gases is generally greater in the liquid state than in the solid state; therefore, most of the gas holes are the result of the gases coming out of solution upon solidification rather than from gas bubbles caused by turbulence as the metal passes through the gating system.

When the metal starts to solidify, solidification progresses from the outside to the inside of the casting. This condition of having a partially solid and a partially liquid zone growing from outside inward is referred to as progressive solidification. The gating system should be designed in such a way that the additional metal required due to shrinkage in this type of solidification, will be supplied without isolating active feed channels to any part of the casting. This is called directional solidification. In some

cases, the shrinkage which occurs when metal freezes may result in either such local effects as cavities or a spongy mass of interconnecting voids, or microporosity. Porosity occurs due to the dissolved gases that are evolved during solidification. In some cases it is widespread and causes microporosity and these gases create a back pressure which makes it difficult to feed through the mush range.

Progressive solidification is a product of the freezing mechanism and cannot be avoided. But the degree of progressive solidification can be controlled. Directional solidification is a product of casting design, location of gates and risers and the use of chills and other means for controlling the freezing process. Hence, it is subject to controls available to the foundryman. The extra metal needed for the casting due to solidification shrinkage is supplied by a reservoir referred to as a riser or head. Risers are attached to the casting at the right location to fulfill their purpose. Usually the heavier section of the casting is on the top since, when pouring a mold, the metal needed for thinner sections can be fed by gravity. A general porosity might occur in the heavier section due to lack of metal flowing by gravity. To prevent this, a riser is attached to the heavier section of the casting which supplies metal for the shrinkage in the heavier section.

The devices used to feed the cavity of the mold have two functions. One function is to deliver metal to the cavity and, secondly, they act as a reservoir when pouring is stopped. The device used for delivery is termed the gating and the device which acts as the reservoir is called the riser. It is difficult to make distinction between these two since one of these could serve both purposes.

The elements of a basic and very common gating system[11] are the down-sprue through which metal enters the runners, and from which it in turn passes through the ingates into the mold cavity. The part which regulates the rate of pouring is called the choke. A pouring basin placed at the top of the sprue minimizes splash and turbulence and promotes the entry of clean metal into the down-sprue. A splash core or well is placed at the sprue base or wherever the flowing metal impinges with more than normal force.

Castings of heavy sections or of high shrinkage alloys commonly require risers where metal stays liquid while the casting is freezing. The riser makes up for the shrinkage in the casting when molten metal flows from the riser to the casting. Depending on the location, the riser is described as a top riser or side riser or bottom riser and may be an open riser or a blind riser. Riser height and neck (junction of riser and casting) are important dimensions of the riser. In some cases, castings are riser-gated to take advantages of the principle of controlled directional solidification.

The functions of an ideal gating system for aluminum castings are: 1) to fill the mold, 2) to introduce molten metal into the mold with as little turbulence as possible to minimize absorption of gases, dross formation, and mold erosion, 3) to introduce proper skimming action on the metal as it flows through the gating system, 4) to regulate rate of entry of metal into the mold, 5) to establish the best possible temperature gradient in the casting, and 6) to produce a casting with a minimum excess of metal in the gates and risers.

The Gating System in The Full-Mold Process

The gating system includes the sprue, runners, ingates and risers. Sprues and risers in the full-mold process are made of styrofoam as is the pattern.

Risers can be either top, side or bottom risers and should be blind risers to prevent excessive flames and smoke. Gating can be accomplished by simply extending a portion of the pattern and pouring the metal into the projection. This method sometimes results in the collapse of the sand around the top of the sprue. Sprue collapse and catastrophic failure of the sprue are new casting problems associated with this method and are not usually observed in the conventional sand molding process. Sprue design is a key portion of the gating system. Gating ratios of 1:2:2, 1:4:4, and 1:6:6 (ratio of sprue area to the runner area to the ingate area) are used in unpressurized systems. For the light metals, tapered sprues will eliminate aspiration of air from the sprue walls into the metal stream. Aspiration,of course, may cause gas entrapment and damaged metal. Rectangular cross-section sprues are considered less likely to develop a vortex than round ones. Sprues should be large enough to supply metal to the gating system but smaller in area than the sum of the ingate areas. This will discourage metal turbulence. Usually the sprue cross-sectional size is ½" x ½" for castings weighing less than 25 pounds. If metal is poured directly into the sprue, a high velocity, turbulence, formation of a vortex and mechanical washing of dross into the mold are all favored. A pouring basin is used to prevent these difficulties. The basin of this type may be formed in the mold. The pouring basin minimizes cascading of the first metal into the sprue and permits the pourer to reach an optimum pouring speed before any metal enters the sprue.

The runner is attached at the base of the sprue and hence there is a sharp curve in the direction of the flow of the metal. This change in direction could cause turbulence, aspiration and damaged metal. To prevent this, a sprue will may be attached and has the side equal to the side of runner or the cross-sectional area of the runner is equal to the sprue well area. The

depth of the well is twice the size of the runner. The purpose of the runners is primarily to carry the metal to different ingates. The runner has a cross-sectional area equal to twice the sprue base area.

The ingate is the section of the gating system which attaches a casting to the rest of the gating system. The ingate may be at the top, bottom or side of the casting. The location of the ingate is very important. The area of the ingate, if there is only one, will be equal to the area of the cross-section of the runner. A projection of the runner beyond the ingate is adviseable since this may provide protection from the turbulence created at the junction of the runner and the ingate.

Risers, as noted above, are the reservoirs for the extra metal needed to overcome the shrinkage and to avoid shrinkage cavities. While designing the risers, solidification of the casting and also the solidification of the riser should be taken into account. The riser should be designed in such a way so that the riser stays liquid until the casting is solid. The location and the distance of the riser from the casting should be studied. There is always a possibility that shrinkage is created at the junction of the casting and the riser since the metal has not solidified here until after the rest of the casting has. The metal stays liquid for a long time since it is near the riser. Overheating of the sand in one location may result in surface shrinkage because of weak skin formation. Overheating is created by placing the riser too close to the casting. Hence the riser should have a neck at the junction of the casting and riser. The height of the riser is kept equal to the diameter of the riser. There are a few formulas used to calculate the dimensions of the risers depending on the casting thickness to be fed and the casting volume.

The Objectives of This Research

The main purpose of this research is to experimentally study possible gating systems for the full-mold process in order to develop a gating system for producing sound castings by:

1. determining the best location for the gates and risers,
2. developing dimensional relationships between the various parts of the gating system and the casting to be produced by using methods similar to ones used in conventional sand molding, and
3. varifying some of the results obtained in prior studies reported in the literature.

EXPERIMENTAL PROCEDURE

Using styrofoam patterns in green sand molds, the gating system for the full-mold casting process has been studied. Some properties of the sytrofoam used for the patterns are given in Table I.

In pouring castings, one of the main considerations is the complete filling of the heavier sections of the casting. For this experiment the pattern considered was quite heavy. Defects may result due to bad design or location of gates on a heavier section of casting. In order to study the complete filling of heavier sections, styrofoam patterns of a test casting 3 inches in length, width, and height were cut from a sheet of the styrofoam material. The gating system for the patterns was also made of styrofoam. The gating system used was similar to the one used for conventional sand molding processes. Parts of gating systems such as sprue, runner, sprue well, ingate were all used as shown in Fig. 4. A riser and a riser neck were also used in these experiments as shown in Fig. 5. All the parts of the gating system were square in cross-section. The dimensions for the parts of the gating system were calculated from the relationship given in Table II used for the conventional sand molding processes.[12] For castings less than 25 pounds, the cross-section of the base of the sprue used in the conventional sand molding techniques is ½" x ½" square. The sprue used in this work had dimensions of ½" x ½" square at the base and the area at the top of the sprue was calculated from the formula[13]

$$\frac{A_1}{A_2} = \frac{\sqrt{Z_2}}{\sqrt{Z_1}} \tag{1}$$

where A_1 is the area of sprue at the top or entrance, A_2 is the area at any other location in the sprue (in this case, A_2 = 0.25 square inches, the area

TABLE I.

SELECTED PROPERTIES OF STYROFOAM

Property	
Density	$\sim$ 1.25 lb./ft.^{3}
Heat Resistance	170° F (77° C)
Compressive Strength	13-16 psi
Shear Strength	160 - 215 psi
Tensile Strength	31 - 48 psi
Vaporization Temperature	400° F (204° C)

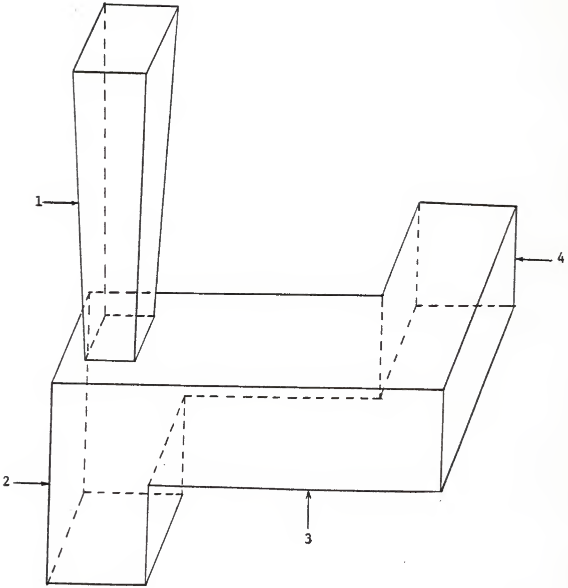


Fig. 4. Parts of gating system used in this work:

1. Sprue
2. Sprue well
3. Runner
4. Ingate

(Roughly Actual Size)

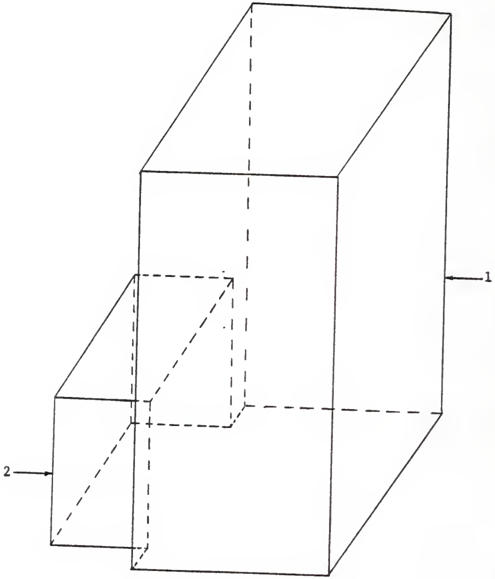


Fig. 5. Parts for risering castings used in this work:

1. Riser   2. Riser Neck

(Roughly Actual Size)

TABLE II.

THE RELATIONSHIP BETWEEN THE DIFFERENT PARTS OF THE GATING SYSTEM (from ref. (12))

Part of Gating System	Cross-sectional Area
Sprue base	A
Sprue top	2A - 3A
Runner	2A
Ingate	2A
Sprue well	2A

of the base of the sprue), Z_1 is the level of pouring basin above the sprue entrance (in this case, 1 inch), and Z_2 is the distance from the top of pouring basin to the location of A_2.

The height of the sprue was kept constant at 3 inches in order to fit the molding flask height. The calculated area of the sprue at the top was 0.5 square inch. Each side of the sprue top calculating from the area of the sprue top was 0.707 inch. For this experiment the cross-section of the sprue top used was 3/4" x 3/4".

The cross-sectional area of the runner was calculated using the relationship given in Table II. The cross-sectional area of the runner was 1 square inch (1" x 1"). The length of the runner was kept constant at 3". The depth of the sprue well was twice the width of the runner. Hence the depth of sprue well was 2" and the cross-section was 1" x 1". The ingate used was a cube with 1" dimensions on each side. Some of the ingates used were made with a cross-section 1" x 1/2" and length equal to 1". The cross-sections of some of the sprues used were larger.

The riser and the neck of the riser were cut separately. The height of the riser was determined from the location of the ingate. The dimension of the sides of the risers were then calculated. In the conventional sand molding processes circular cross-sectional risers are used but for this work a square cross-section was used. The top of the riser was kept level with the sprue entrance. The height of the riser was then determined from the location of the riser. The volume of the riser was found by first obtaining the shape factor of the casting to be produced. In this case the casting had a shape factor of 2 since it was a cube. The shape factor can be calculated from the formula[14]

$$\frac{L + W}{T} \qquad (2)$$

where L is the length of casting, W is the width of casting, and T is the thickness of the casting. The ratio of the riser volume to the casting volume is found to be 0.81, from Fig. 6. From this, the volume of the riser was calculated to be equal to 21.87 ≈ 22 cubic inches. The cross-sectional area of the riser was calculated by dividing the appropriate height of the riser. The square-root of this area was then the side of the riser, W_R.

The neck of the riser also had a square cross-sectional area. The distance between the riser and the pattern, which is the riser neck length, L_N, was half the width of the riser. The side of the riser neck W_N, was calculated from the formula[11]

$$W_N = 1.2\ L_N + 0.1\ W_R \qquad (3)$$

In some cases, the length of the riser neck used was 1 inch and the width of the riser neck was half the width of the riser. In the conventional processes, there are formulas used for calculating the riser neck dimensions for different types of risers used. The formula used in this work was for general type of risers and was modified by using the width of the riser neck, W_n, in place of the diameter of riser neck, D_n, and the width of the riser, W_R, in place of the diameter of the riser, D.

Table III gives the basic dimensions used in these experiments calculated according to the procedure shown above. The gates and risers were attached to the pattern at three different positions. The gates and risers are known as top, bottom and side according to the position where these are attached to the pattern. A top gate is a gate attached to the pattern at the top edge of

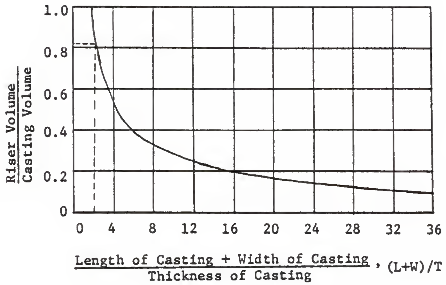


Fig. 6. The relationship between the casting shape factor and the minimum effective riser volume as a fraction of casting volume. (From ref. 14)

TABLE III.

GENERAL DIMENSIONS FOR VARIOUS PARTS
OF THE GATING SYSTEMS USED IN THE EXPERIMENTS.

Gate	Riser	Riser Height in.	Length of Side of Riser in.	Riser Distance From Casting in.	Length of Side of Riser Neck in.
Top	Bottom	6	1.9	0.95	1.3
Side	Bottom	5	2.1	1.05	1.5
Bottom	Bottom	4	2.4	1.2	1.7
Top	Side	4.5	2.2	1.1	1.5
Side	Side	3.5	2.5	1.25	1.75
Bottom	Side	2.5	2.96	1.48	2.1
Top	Top	3	2.7	1.35	1.9
Side	Top	2	3.3	1.65	2.31
Bottom	Top	1	4.7	2.35	3.29

the pattern. A bottom gate is a gate attached at the bottom edge of the pattern. A side gate is a gate attached at the center of the side of the pattern. Similarly the risers were attached to the pattern at the same position but on the side of the pattern opposite that to which the gates were attached. In Table III each horizontal row gives the dimensions for a particular combination of gates and risers.

All of the parts of the gating system and the pattern were cut by heated nichrome wire for the initial experiments. These parts were subsequently cut with a band saw for later experiments. Having cut all the parts accurately, the various members were assembled into the desired pattern and gating system with a glue especially made for bonding styrofoam, white foam, and styrene beads. The glue used vaporizes along with the pattern material. An assembled styrofoam pattern as used in these experiments is shown in Fig. 7.

The molding sand used in these experiments was a conventional sand used for green sand molding. The Standard American Foundrymens Society (AFS) tests to determine the grain size and the clay content are performed with the results tabulated in Table IV.

A sample of 50 grams of dried molding sand was put into a wash bottle and was washed according to the following procedure:

1. Add 475 ml. distilled water and 25 ml. caustic soda solution (25 grams of NaOH per liter).
2. Agitated for 5 minutes with mechanical stirrer, diluted with water to a height of 6 inches (marker of bottle), and let settle for 10 minutes.
3. Siphoned off 5 inches water, diluted again to 6 inches height, and let settle for 10 minutes.

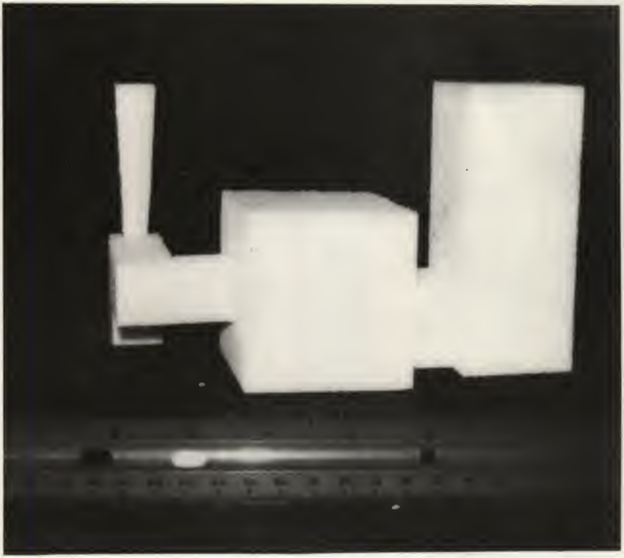


Fig. 7. Styrofoam pattern as assembled.

TABLE IV.

AFS GRAIN FINENESS NUMBER FOR THE MOLDING SAND

Size of Samples: 50 grams
AFS Clay Content: 2.98 grams or 5.96%
Sand Grains: 47.02 grams or 94.04%

U.S. Series Equivalent Number	Tyler Screen Series	Amount of 50-gram Sample Retained on each Sieve		Multiplier	Product
		Grams	Percent		
6	6	1.48	2.96	3	8.88
12	10	0.90	1.80	5	9.00
20	20	0.89	1.78	10	17.80
30	28	5.71	11.42	20	228.40
40	35	1.51	3.02	30	90.60
50	48	7.41	14.82	40	592.80
70	65	6.66	13.32	50	666.00
100	100	5.03	10.06	70	704.20
140	150	3.27	6.54	100	654.00
200	200	6.07	12.14	145	1760.30
270	270	3.55	7.10	200	1420.00
Pan		6.70	13.40	300	4020.00
	Total	49.18	98.26		10171.98

$$\text{AFS Grain Fineness Number} = \frac{\text{Total Product}}{\text{Total Percentage of Retained Grain}} = \frac{10171.98}{98.36} = 103.42$$

4. Siphoned off 5 inches water, diluted again to 6 inches height, and let settle for 5 minutes.
5. Repeated step 4 enough times so that, after standing 5 minutes the water was clear.
6. The remaining sand grains were removed from the bottle, dried and weighed. The loss in weight of the original 50 gram sample, which was 2.98 grams, multiplied by 2 gave the AFS clay content of the sand to be 5.96 percent.

An AFS sieve analysis was performed to determine the size and distribution of the sand grains in the sand. The dried sand-grain residue from the clay content determination was used. The sample was placed on top of a series of sieves and shaken for 15 minutes. The sand retained on each sieve and the bottom pan was weighed and its percentage of the total sample determined. The percentage retained on each sieve is multiplied by a factor which is the size of the preceding sieve that is the actual size of sand grains retained on one sieve that are permitted to pass through the preceding sieve. The product of the sieve numbers multiplied by the factors were summed. Then the average grain fineness number is equal to the sum of the sieve number and factor product divided by the total percentage of sand grains retained in the sieve set and pan. The computed AFS grain fineness number for the molding sand was found to be 103.42.

For making the molds, water was added to the sand as it was mechanically mixed in the muller to obtain the correct moisture content. A flask, as shown in Fig. 8, was placed on a wooden bottom board and a sand bed was made on the bottom board. The completed pattern, as shown in Fig. 7, was placed on the sand bed and additional sand was hand packed around the pattern. A second flask

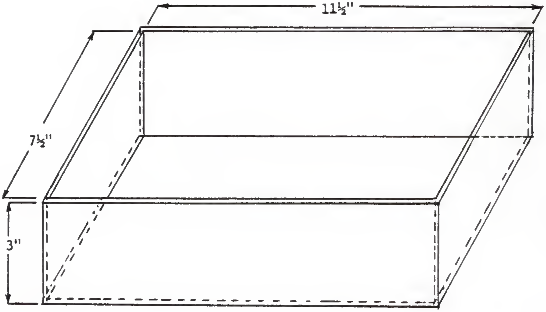


Fig. 8. Sketch of flask used in these experiments.

was placed on top of the first one to achieve a height greater than the height of the pattern by at least 1 inch. Precautions were taken to pack the sand inside any cavities or depressions in the patterns. The entire pattern was covered with sand including the riser and the sprue. More than one inch of sand was packed over the sprue. A pouring base was cut near the sprue and a channel was cut attaching the top portion of the sprue and the pouring basin. This top portion of the sprue was the only part visible in the finished mold. All the molds were made by hand molding.

The metal used in these experiments was the aluminum alloy used in the Industrial Engineering Department foundry. The temperature of the metal was about 1250° F (700° C) when poured. Metal was poured manually with a hand ladle as shown in Fig. 9. The rate of pouring was kept as fast as necessary to keep the pouring basin full and the sprue covered with the metal at the junction with the channel. The rate of pouring during the pour was kept constant. The aluminum was melted in an induction furnace with a capacity of about 200 pounds. Each mold was poured using a freshly filled ladle of molten aluminum.

The molds were broken the day after each pour, after about 20 hours. Fig. 10 shows the solidified casting after being shaken out of the mold. All of the gating system and the riser are still attached to the casting shown in the figure. All the castings were visually examined for surface defects. All of the castings, even these which appeared externally sound, were sectioned using the band saw and examined for internal defects.

Fig. 9. Manual pouring of metal into the mold. Note the slight wisp of vaporized styrofoam escaping to the right of the molten metal stream.

Fig. 10. Casting with gating system attached after shake-out.

RESULTS AND DISCUSSION

The Gating System

Nine combinations for the arrangement of the ingate and riser positions were studied in these experiments. The nine consisted of three different gate positions and three different riser positions. The gates were attached to the pattern on one side of the cubical pattern and the risers were attached to the opposite side of the pattern. The gate positions, namely top gate, bottom gate, and side gate, were at the center of the top edge of the side of pattern, at the center of the bottom edge of the side of pattern and at the center of the side of the pattern respectively. Similarly, the risers were attached at the center of the top edge, bottom edge and center of the side of the pattern. For each position of the gate there was one riser position. If, for example, the gate was at the top edge of the side of the pattern then for that pattern the riser was attached at the top edge of the opposite side of the pattern; then, for another pattern with the gate still at the top edge of the center of the pattern, the location of the riser would next be at the center, as shown in Fig. 11. Finally, with the gate still at the top edge of the side of the pattern, the location of the riser would be at the center of the bottom edge of the opposite side of the pattern as shown in Fig. 12. For the next pattern the position of the gate was in the center of the bottom edge of the side of the pattern. Repeating the three different positions of the risers, as discribed above, made three combinations and similarly the position of gate at the center of the side of the pattern with the three positions of the risers made three more combinations, which gave the total combinations of nine. Each completed pattern was different than the other either by the location of the gate position or by the location of the

Fig. 11. A pattern with a top gate and a side riser.

Fig. 12. A pattern with a top gate and bottom riser.

riser position. With these combinations the patterns were molded and poured in several heats.

The position of the ingates and risers has a great influence on the soundness of the casting and filling the mold. Table V summarizes the results of these experiments as determined by examination of the castings for internal defects. The defects found were mainly shrinkage, shrinkage cavities, and porosities. The combination bottom-gated bottom-risered, side-gated top-risered, side-gated bottom-risered and bottom-gated side-risered were found to produce good castings. In some of the castings there was a cavity in the center of the castings as shown in Fig. 13. The controlling factor here is the period of time the metal remains in the molten state in the mold. In this case, the casting was a cube where the walls freeze first and draw metal from the still molten center. Where no further metal is available to compensate for this loss, the center of the casting will show a cavity. Where a shrinkage cavity shows up close to the ingate, it may be traced to a gate faulty in design or shape. This was observed in this experimental work when the dimensions of the gates were varied. In many instances the cross-sectional area of the gate is an important factor and this factor is a variable depending on the thickness of the casting at the point where the gate is attached.

On a thick or comparatively thick casting, as in this case, a wide thin gate will solidify while the metal in the mold still is molten. Consequently the casting must depend on other factors to take care of the ensuing shrinkage. Metal in a gate a little thicker will remain liquid for a longer period, but where it solidifies while the shrinking metal in the casting still is feeding from the point a defect known as a draw is developed. In other words, the line of communication is shut off and the metal in the casting at that

TABLE V.

SUMMARY OF RESULTS FOR THE NINE COMBINATIONS FOR THE ARRANGEMENT OF THE LOCATION OF THE GATES AND THE RISERS STUDIED IN THE EXPERIMENTS.

Riser \ Gate	Top	Side	Bottom
Top	NG*	OK**	NG
Side	NG	NG	OK
Bottom	NG	OK	OK

*NG = No good, defective casting.

**OK = Good casting.

Fig. 12. Cavity in the center of the casting.

point is drawn inward. The ideal result is obtained by a large gate well backed by a generous sprue in which the metal will remain fluid and feed the casting, either until the entire casting has solidified, or until the section in immediate contact with the gate has solidified to a point where any danger of a draw is eliminated.

In some castings dispersed shrinkage cavities were observed, especially toward the center of the section as shown in Fig. 14. This is a center-line type of shrinkage and is governed greatly by size and shape factors of the casting sections. The size and shape factor is related to the distance that may be fed from risers into the casting whether located as top or as bottom or as side risers. From the experiments, it was observed that when the distance that may be fed from the riser is decreased the center line shrinkage was prevented.

Molding sand. Careful control in sand quality and uniformity gave good results for the surface finish of the castings. The correct amount of moisture in the sand helped in packing the sand around the pattern for a uniform compactness when hand molding was used. When the sand was loosely packed, the surface finish was rough and in some places metal penetration into the sand was observed. At the same time some surface defects were found when the sand was tightly packed in the mold.

Pouring. The aluminum alloy was melted and poured at about 1250° F (700° C). In the initial stages of pouring, the rate was less but suddenly the rate had to be increased and again the pouring rate had to be decreased at the end of pouring. There were fluctuations in the rate of pouring. The pouring rate was kept at a rate necessary to cover the portion of the sprue which was exposed initially when the pouring started. This was done to prevent

Fig. 14. Center-line shrinkage as seen in a sectioned casting.

the vaporizing styrofoam from escaping from the mold and required a good design for the pouring basin. The time needed to fill the lower part of the pouring basin up to the entrance of the sprue was enough to determine the rate of flow needed for the casting. It was found that sand should be packed at least one inch over the entrance of the sprue. Initial tests indicated that the riser should be a blind riser covered with at least one inch of sand. When, while pouring, the sprue was not kept covered, the castings were found with sand inclusions. Basically, the reason for this was due to the escaping vapors which otherwise prevent the sand from falling into the flowing metal.

The relationship between the various parts of the gating system used, as shown in Table II, worked satisfactorily for the combinations of variables considered in this work. Use of Eq. 3 for the dimensions of the riser neck and the procedure used for determining the riser dimensions, as described in the Experimental Procedure, gave good results.

The dimensions of the gating system, riser, and riser neck were varied from the originally calculated dimensions several times. The results show defective castings when the dimensions of the gating system were reduced and also when the riser and riser neck dimensions were increased. When the riser neck length was increased there was a center-line shrinkage observed in the casting. In some cases, solidification shrinkage took the form of pinhole porosity. This was found when the neck dimension was decreased which resulted in a lack of an adequate supply of molten metal to the casting. A shrinkage defect may or may not show on the surface of a casting. This type of defect may seriously affect the strength of the casting and cannot be tolerated in castings subjected to severe service stress.

Defects of a surface character may be detected readily and proper measures may be taken to correct them. If the defect is internal, for example shrinkage or porosity, a number of castings may have to be made before the proper preventative measures can be applied.

Porosity in the full-mold castings in many instances is due to the difficulty experienced in controlling the shrinkage during the period the metal is passing from the liquid to the solid state. Porosity may be prevented or greatly reduced by careful control of all the factors involved, temperature of the metal, pouring practice, gating and feeding. Proper location and size of the gate risers, moisture and physical properties of the sand, construction of the mold, are also important.

CONCLUSIONS

This experimental research has dealt primarily with the gating system and the risering for producing sound castings by the full-mold process. The location, shape and the dimensions of the gating system and the risering are important for producing sound castings economically, easily and for mass production. From this experimental work, it can be concluded that:

1. Styrofoam is a good pattern material for the full-mold process. Styrofoam is not expensive and commonly available. Styrofoam can be cut into any shape with a heated nichrome wire or can be cut by a bandsaw without much difficulty. Styrofoam can be easily assembled into complex pattern shapes.
2. The shape of the gating systems used was square in cross-section throughout the experiments and was found to work satisfactorily for the pouring technique used and for the height of the sprue used. Square cross-sections of the gating systems should be tried on larger castings using various pouring methods and with different dimensions for the sprue and the other parts of the gating system.
3. Certain combinations for the location of the gating system and the risers produce better castings than do other combinations. In this work, bottom-gated bottom-risered, bottom-gated side-risered, side-gated top-risered and side-gated bottom-risered produced more acceptable results than the other combinations studied.

4. The dimensions and the relationships used for the various parts of the gating system used for conventional pattern making can be used for producing patterns for casting by the full-mold process with little modifications. Castings with combinations of thick and thin sections should be examined. Further modifications may be needed for heavier castings.
5. The manual pouring rate can be made constant and the rate at which the metal should be poured into the mold can be controlled through the use of a pouring basin.
6. Foundries using conventional sand molding processes for producing castings should be able to adopt the full-mold process without much difficulty.

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A STUDY OF THE GATING SYSTEM OF CASTINGS

PRODUCED BY THE FULL-MOLD PROCESS

by

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ABSTRACT

In this research, a study of the gating system for the full-mold process was performed. The objective of this research was to develop a gating system for producing sound casting. The experimental study consisted of three areas of interest. First, to determine the best location of the gates and risers. Second, to develop dimensional relationships between the various parts of the gating system and the casting to be produced by using methods similar to ones used in conventional sand molding. Third, to verify some of the results obtained in prior studies. The objectives of this work were achieved through the use of styrofoam as the pattern material, manually molded in green sand. Nine combinations for the location of the gates and risers were examined. An aluminum alloy was used as the casting metal.

The study shows that styrofoam is a good pattern material for the full-mold process. Four combinations of gates and risers produced more acceptable results than the other combinations studied. The square cross-sectional shape for the gating system used in this experimental study, was found to work satisfactorily for the type of pouring used and the height of the sprue used. The relationship between the various parts of the gating system, similar to relationships used in the pattern making for conventional sand molding processes, gave satisfactory results with the correct combination for the location of the gates and risers. The experimental results indicate that with the use of a pouring basin, the manual pouring rate can be made constant and the rate at which the metal should be poured can be controlled. The basic reasons for the surface finish obtained and the surface defects observed are discussed.